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Calculation of the Critical Value Price of Distributed Generation Considering Transmission Loss Cost

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Abstract

For the open electricity market, the price of distributed generation (DG) will directly affect power producers and power supply enterprises operating costs. Generation cost of DG is higher than conventional power, in the absence of policy support and financial subsidies, there is not enough power to buy electric from DG; However, because of its characteristics, DG could reduce transmission losses to a certain extent, thereby reducing the cost of power grid. So generation cost difference between DG and conventional power generation does not accurately reflect the amount of subsidies, the pricing and subsidy policies is essential. In this paper, only considering transmission losses, on this premise, DG pricing critical value is proposed and calculated aiming at the transmission cost does not increase after fixing DG basing on node transmission cost analysis based on power dependency trace. If DG price is equal to the critical value, which indicate that benefits by reducing the transmission loss is enough to compensate for the losses caused by higher costs. If the price is higher than the critical value price, power system should be subsidized, and accurately calculate the amount of subsidies. Finally, IEEE9 node system example shows the feasibility of the method.

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Keywords: *Generation price, cost conservation, power decomposition, node price, distributed generation*

1. Introduction

In recent years, distributed generation (DG) is being greatly improved in each country considering the scarce of primary energy source and the improving function for power grid made by DG. However, for power grid enterprise, there is competition with power generation enterprise and strictly control for sales price. Under these double pressures, when power grid enterprise chooses power supply, the primary

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consideration is its cost, though DG has various advantages. Therefore, the generation price of DG appears especially important, the importance lies not in whether could bring profit to the enterprise, but lies in whether could bring a long-term fair competition environment to the whole industry.

Reference [1-4] introduced various calculation methods for the generation price of DG, which started from DG itself considering the initial investment, annual energy production and operation cost and so on to calculate the generation price of DG. The DG mainly generate by the natural gas, wind and other new energy resources, at present the generation cost of DG is approximately 0.7 Yuan which is much higher than stake electrovalence of thermal power plant. There are a plenty of pricing methods to calculate generation price at home and abroad, which can be mainly reduced to three types as government pricing, contractual pricing and pricing by competition [5-13]. Judging by the formation mechanism and the developing trend of generation price, it is an inevitable process that pricing mechanism developed form government pricing by administrative means to the market-oriented pricing mechanism [14-15]. But the DG industry is a newly starting undertaking whose construction cost and operating costs are far more than the same scale coal-fired power project, and the price structure, influence factors and the change rule are also different from the traditional power. Therefore, to maintain the development of DG industry healthy and sustainable, confirming the generation price and the government subsidies amount through the market and the competition is inevitable. Because of its characteristics, DG could reduce transmission losses to a certain extent, thereby reducing the cost of power grid. So generation cost difference between DG and conventional power generation does not accurately reflect the amount of subsidies, the pricing and subsidy policies is essential. In this paper, only considering transmission losses, on this premise, DG pricing critical value is proposed and calculated aiming at the transmission cost does not increase after fixing DG basing on node transmission cost analysis based on power dependency trace. If DG price is equal to the critical value, which indicate that benefits by reducing the transmission loss is enough to compensate for the losses caused by higher costs. If the price is higher than the critical value price, power system should be subsidized, and accurately calculate the amount of subsidies.

2. Cost Analysis and Calculation Method

2.1. Branch electricity price analysis

Any network is made up by single branch, we illustrate with a single branch as an example.

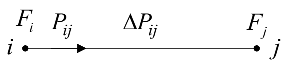

Fig. 1. Single branch power flow diagram

where P_{ij} is the power injected into the branch, $\triangle P_{ij}$ is the branch transmission loss , F_i is the node cost price of sending node i, F_j is the node cost price of receiving node j. According to the principle of cost flow conservation [16], equation (1) is established.

$$F_{\mathrm{i}} P_{ij} = F_j (P_{ij} - \Delta P_{ij}) = F_j P_{ij} - F_j \Delta P_{ij} \tag{1}$$

Shown as in (1), the node cost of receiving node j is higher than the node cost of sending node i, because of $F_j \triangle P_{ij}$ which is named transmission loss cost. Different value between sending node and receiving node can be reduced by reducing transmission loss cost, then make cost of each node reduced; For the contrary, increase of transmission loss cost will lead to the increase of power grid transmission cost.

2.2. Calculation method

Most of DGs are near the load, which will make the transmission losses decrease in a certain degree. As is shown in (1), both of the price of sending node (generation price) and the transmission losses could influence the amount of transmission loss cost. Because its generation price is much higher than conventional power, therefore transmission loss cost must be accurately calculated to determine the influence to transmission loss cost bringing by installing DG.

This paper adopted power dependency tracing method based on power decomposition theory[17-18], Which is a electrical parameter analysis method based on global network expanded and proposed using the classic circuit theory. Power output is decomposed to component forms, which get independent distribution rule of every component in networks; namely, power distribution numerical value of multi-power network can be equivalent to the algebraic sum of power distribution numerical value of several single-power networks. This model fully made use of advantages of power components theory, multi-power network is decomposed to several of decoupling single-power network, each power output is separated independently under the physical significance. Thus power output, branch transmission power and branch loss in each single-power network can be obtained [5].

Beginning with the description of the origin of marginal cost in microeconomics and its introduction into power system, Reference [19] derives the problems existing in current marginal cost method used for calculating power price after analyzing the application premise of both. Therefore, in this paper, node network loss cost analysis model based on cost flow conservation principle is adopted to calculate node cost price [20-22]. Transmission cost conservation principle, namely, the cost injected into branch is equal to the cost flowed out of branch, can ensure the balance of profit and loss fundamentally, thus guarantee the objectivity of transmission costs calculation. Using power dependency tracing method, we have got the distribution of power components provided by single power in the network. Only considering transmission loss, equations can be established for each branch according to the principle of cost flow conservation starting from power node. It can be expressed as (2) for network contains m nodes.

$$\mathbf{B}_{\mathrm{p,ks}}\mathbf{F}_{i,ks} = \mathbf{C}_{G,ks} \tag{2}$$

where in the matrix $\boldsymbol{B}_{p,ks(m\times m)}$, elements $\boldsymbol{B}_{p,ks(ii)} = P_{i,ks}$, $P_{i,ks}$ is the sum of active power flowed into node *i* provided by power *ks*; $\boldsymbol{B}_{p,ks(ji)} = -P_{ji,ks}$, $P_{ji,ks}$ is active power that sending node *j* injected into the branch *j-i* provided by power *ks*; $\boldsymbol{F}_{i,ks}$ is node cost price column vector in single power network containing power *ks*; $\boldsymbol{C}_{G,ks}$ is cost column vector that power *ks* injected into the network (the product of generation price and active power).

Solve (2), node cost price of each node in each single-power network is obtained as (3).

$$F_{i,k\mathrm{s}} = \lambda_{i,ks} \cdot F_{G,k\mathrm{s}} \tag{3}$$

where $F_{G,ks}$ is the cost price of generator node in single power network(generation price); $\lambda_{i,ks}$ is the coefficient obtained by solving (3);

The transmission loss of each branch and node cost of each node in each single power network were known according to the methods introduced above, The model of transmission loss cost in single branch is expanded to the whole grid, then the function of transmission loss cost minimum model is established as (4).

$$\begin{aligned}\rho_{total} &= \sum_{ks\in\beta}\sum_{l\in\alpha} \rho_{l,ks} \\ &= \sum_{ks\in\beta} F_{G,ks} \sum_{l\in\alpha} \Delta P_{l,ks} \cdot \lambda_{l,ks}\end{aligned} \tag{4}$$

where α is branch set; β is generator set; $\rho_{l,ks}$ is the transmission loss cost of branch l in single power network containing power ks, $\Delta P_{l,ks}$ is the transmission loss of branch l in single power network containing power ks.

3. The calculation of critical value price

According to the method introduced above, the transmission loss cost of whole network in which DG is not installed could be obtained. The process is as follows:

1) Calculate the power flow according to the network operation parameters;

2) The generators are equivalent to the current sources; loads are equivalent to admittances;

3) Decompose the power flow results according to power decomposition theory, obtain independently power flow for each power;

4) Calculate the node cost price in each single-power network according to node network loss cost analysis model;

5) Calculate the transmission loss cost of whole network.

According to the same method, the transmission loss cost of whole network in which DG is installed could be obtained as follows:

$$\begin{aligned}\rho'_{total} &= \sum_{ks\in\beta} F'_{G,ks} \sum_{l\in\alpha} \Delta P'_{l,ks} \cdot \lambda'_{l,ks} \\ &+ F_{G,D} \sum_{l\in\alpha} \Delta P_{l,D} \cdot \lambda_{l,D}\end{aligned} \tag{5}$$

where α is branch set; β is generator set except for DG node ; $F_{G,D}$ is the generation price of DG.

DG pricing critical value is proposed and calculated aiming at the transmission cost does not increase, so equation can be established as follows:

$$\begin{aligned}&\sum_{ks\in\beta} F'_{G,ks} \sum_{l\in\alpha} \Delta P'_{l,ks} \cdot \lambda'_{l,ks} \\ &+ F_{G,D} \sum_{l\in\alpha} \Delta P_{l,D} \cdot \lambda_{l,D} = \rho_{total}\end{aligned} \tag{6}$$

The generation price of DG $F_{G,D}$ is set as unknown quantity, the others are set as known quantities. The expression of $F_{G,D}$ is shown as follows:

$$F_{G,D} = \frac{\rho_{total} - \sum_{ks\in\beta} F'_{G,ks} \sum_{l\in\alpha} \Delta P'_{l,ks} \cdot \lambda'_{l,ks}}{\sum_{l\in\alpha} \Delta P_{l,D} \cdot \lambda_{l,D}} \tag{7}$$

The significance of this critical value is that if the generation price of DG is lower than this critical value, it means that the introduction of the DG effectively reduced the transmission loss cost and the operation cost of power grid enterprise. If the generation price of DG is higher than this critical value, it indicates that although the DG made the transmission loss reduced, it rise the transmission loss cost and the operation cost because of its higher price, which determined that power grid enterprise should be subsidized as follow

$$F_{sub} = F_{DG} - F_{G.D} \tag{8}$$

where F_{sub} is amount of subsidy, F_{DG} is the generation price of DG.

4. Example Analysis

Example adopted power system of IEEE 3 generators and 9 nodes, the grid structure is shown as Fig. 2.It contains 6 branches,3 load node, node 1,2and 3 are power injection nodes, node 1 can be regarded as a balance node, node 2 and 3 are PV nodes.

Under determined cross-section, operation parameters of generators and transformers have been determined. The decomposition results of transmission losses could be calculated according to power decomposition theory, as is shown in Table 1.

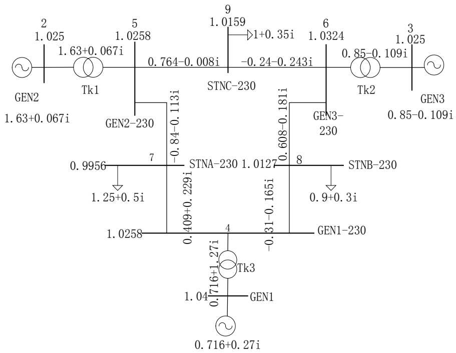

Fig. 2. Power system of IEEE 3 generators and 9 nodes

Calculate the node cost price in each single-power network according to node network loss cost analysis model, as is shown in Table 2.

In Table 2, the generation prices of generators are set as 1. According to (4), the transmission loss cost of whole network is calculated.

$$\rho_{total} = 0.0505$$

Table 1. The loss of each sub-branch on the way(MW)

Branch	GEN1	GEN2	GEN3
8-7	-0.0045	0.0084	0.0009
8-9	-0.0012	-0.0023	0.0043
5-7	-0.0003	0.0261	-0.0017
6-9	-0.0017	0.0035	0.0129
4-5	0.0030	-0.0049	0.0048
4-6	0.0024	0.0037	-0.0036

Table 2. Node price of each Generator in the network

Node	GEN1	GEN2	GEN3
1	1.0000	0.0000	0.0000
2	0.0000	1.0000	0.0000

3	0.0000	0.0000	1.0000
4	1.0000	0.9972	1.0016
5	1.0076	1.0366	1.0201
6	1.0073	1.0157	1.0333
7	1.0054	1.0000	1.0137
8	0.9718	1.0099	1.0091
9	0.9949	1.0028	1.0000

In actual power grid, the maximum output proportion taken up by DG is 10% in whole grid. The node cost price of node 5 is the highest, so the DG is installed at node 5. The capacity of DG is 20 MW which is 5% of the whole grid output. The decomposition results of transmission losses are shown in Table 3.

The results of node cost price are shown in Table 4 in which the generation prices of generators including the DG node are set as 1. As the same, the transmission loss cost of whole network is calculated according to (4).

$$\rho'_{total} = 0.0460$$

Table 3. The loss of each sub-branch on the way after installed DG(MW)

Branch	GEN1	GEN2	GEN3	GEND
8-7	-0.0030	0.0137	-0.0003	-0.0055
8-9	-0.0009	-0.0020	0.0036	-0.0002
5-7	0.0018	0.0141	-0.0048	0.0105
6-9	-0.0011	0.0041	0.0135	-0.0012
4-5	-0.0006	-0.0021	0.0018	0.0015
4-6	0.0032	0.0044	-0.0041	-0.0010

Table 4. Node price of each Generator in the network after installed DG

Node	GEN1	GEN2	GEN3	GEND
1	1.0000	0.0000	0.0000	0.0000
2	0.0000	1.0000	0.0000	0.0000
3	0.0000	0.0000	1.0000	0.0000
4	1.0000	1.0016	1.0032	1.0271
5	0.9980	1.0178	0.9962	1.0000
6	1.0136	1.0256	1.0346.	1.0089
7	1.0171	1.0000	1.0062	1.1637
8	0.9831	1.0160	1.0077	1.0139
9	1.0027	1.0099	1.0000	0.9673
10	0.0000	0.0000	0.0000	1.0000

Compare ρ_{total} and ρ'_{total}, if the generation price of DG is set as 1 which is equal to conventional power, the transmission loss cost has been reduced after installed the DG. Considering the generation price of DG is much higher than conventional power, if the generation price of DG is set as 3, the transmission loss cost of whole network is calculated.

$$\rho'_{total} = 0.0536$$

As is shown, the transmission loss cost has been increased. Then we set the generation price of DG as unknown quantity to calculate the critical value according to (6) and (7).

5. Conclusion

Devote major efforts to developing distributed generation and using environmentally energy sources is the policies and principles of our country, but the affordability of power grid enterprise should be also considered. The key problem of network access of DG is to straighten out the price mechanism, so how to price and subsidize is the most important for the development of DG industry. In this paper, the critical value of generation price of DG is calculated basing on node transmission cost analysis based on power dependency trace, and defined the amount of subsidy. The transmission cost could be accurately accounted which will effectively guide the formulation and implementation of pricing policies for DG.

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